RESEARCH POTENTIAL OF SPACECRAFT DEBRIS IN THE NASA COSMIC DUST COLLECTIONS.

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Introduction: Spacecraft de-orbit events generate debris which spans a range of sizes, from dust-sized to large fragments. A recent paper demonstrated that a measurable amount of spacecraft debris is present in stratospheric dust, entrained in sulfuric acid droplets present at that altitude [1]. Spacecraft launches are increasing in number, and with them an increasing amount of infall debris is generated. The NASA Cosmic Dust Collections include possible spacecraft debris to include the examples shown here. At present the scientific potential of spacecraft debris in the collection has not been fully explored.

Potential Avenues of Research: Research into spacecraft debris infall ranges from scientific interest [e.g. 2] to hazard risk assessment [many, e.g. 3-5] and debris mitigation [6]. Recently the latter has expanded into understanding hazards to aircraft posed by debris [7]. The pace of spacecraft launches is expected to grow in the near term (Figure 1), driving a need for improved understanding of the infall flux.

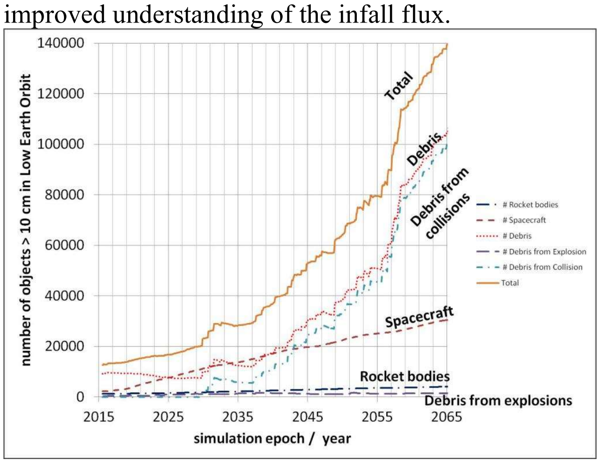

Figure 1: Model results showing future population of man-made objects in low Earth orbit. Debris infall can be expected to increase in the near term. From [8].

Possible Spacecraft Debris in the NASA Cosmic Dust Collections: The NASA Cosmic Dust Collections is a collection of dust particles collected from the upper atmosphere and micrometeorites collected from water wells at the South Pole. Dust is collected by high altitude aircraft using adhesive collection plates, to comprise the Aircraft Collected Particle (ACP) collection. ACP collection has occurred nearly continuously since 1981 with a large number of particles available for request. ACP particles are

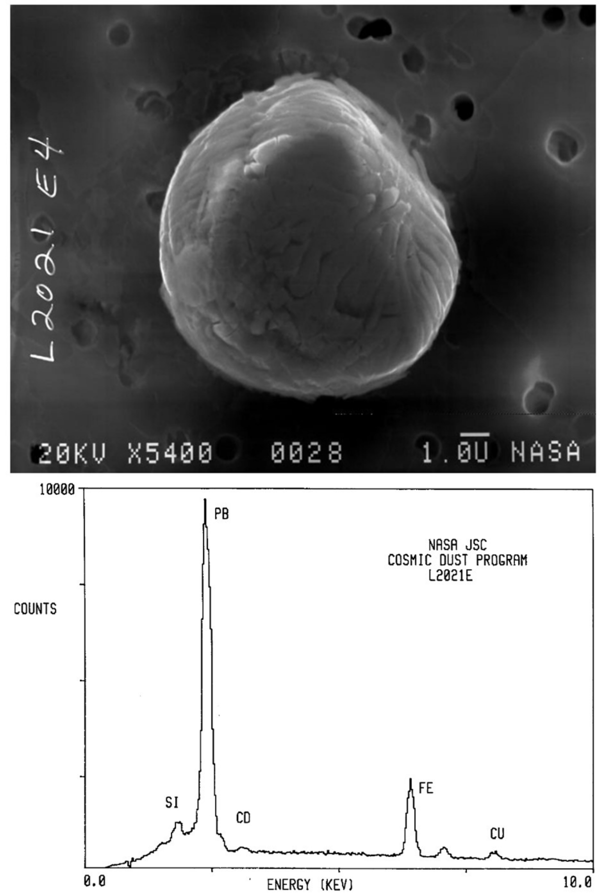

Figure 2: L2021E4. Possible spacecraft-origin spherule with an appearance consistent with complete or partial melting. The composition of this particle is not consistent with cosmic particles but may originate from a spacecraft component including lead solder (Pb). Minor Fe, Si, Cd, and Cu require origination from a complex structure.

“picked’ from their collectors, rinsed in hexane to remove the adhesive oil, and analyzed using SEM/EDS before being announced as available to the community. Particles are given a preliminary classification based on appearance and composition – primarily between cosmic or possibly cosmic (C or C?), terrestrial contamination of natural origin (TCN), or terrestrial contamination of artificial origin (TCA). The TCA category contains spacecraft debris alongside objects such as paint flakes and cadmium oxide from the aircraft, iron oxide (rust) fragments, aluminum oxide spherules from solid rocket motors, and other objects.

Analysis of Cosmic Dust particles is intentionally rudimentary, with the goal of providing enough information for an investigator to make an informed sample request but steering clear of scientific investigation of the particles.

At present there is no category specifically for spacecraft debris and a protocol for identifying it may need to be developed, based on input from the community. Spacecraft-origin particles may be identified by their non-natural elemental composition and by their texture. Elements such as gold (from electronics components), titanium and/or aluminum (from structural components), and rare earths from solar panels and electronics may signal a spacecraft-origin particle. The following particles are presented as potential remains of spacecraft. This is not a complete representation, as other types of spacecraft materials likely exist.

The Cosmic Dust Collections' ACP collection is a largely unexplored resource for study of spacecraft debris. As with all NASA collections, the Curator is available to assist with research inquiries (marc.d.fries@nasa.gov).

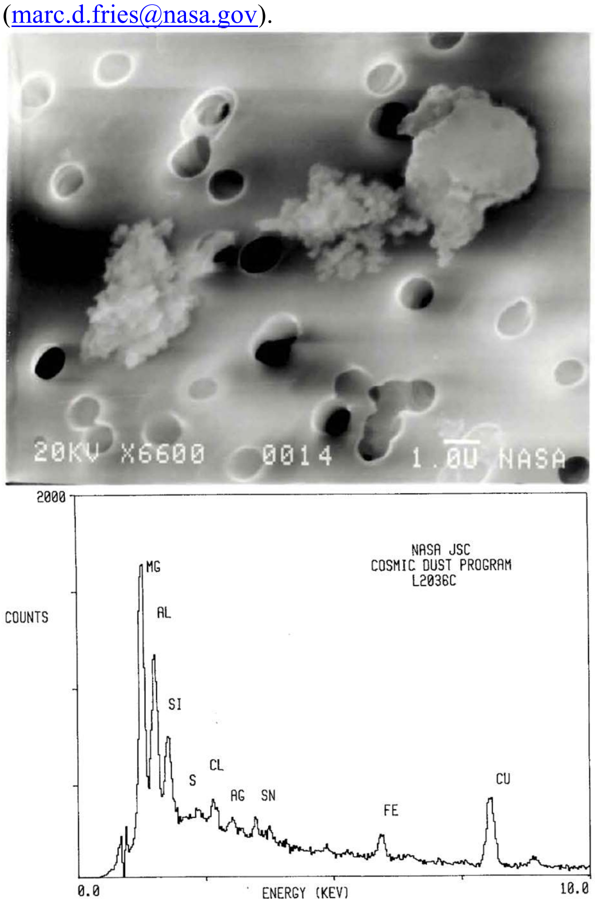

Figure 3: L2036C4. This particle has a complex composition possibly consistent with a spacecraft origin, with Mg, Al, Si combined with Ag, Sn, Fe, and Cu. This particle is a fluffy aggregate possibly captured in a sulfuric acid particle, and may contain materials from multiple sources (chondritic + spacecraft?).

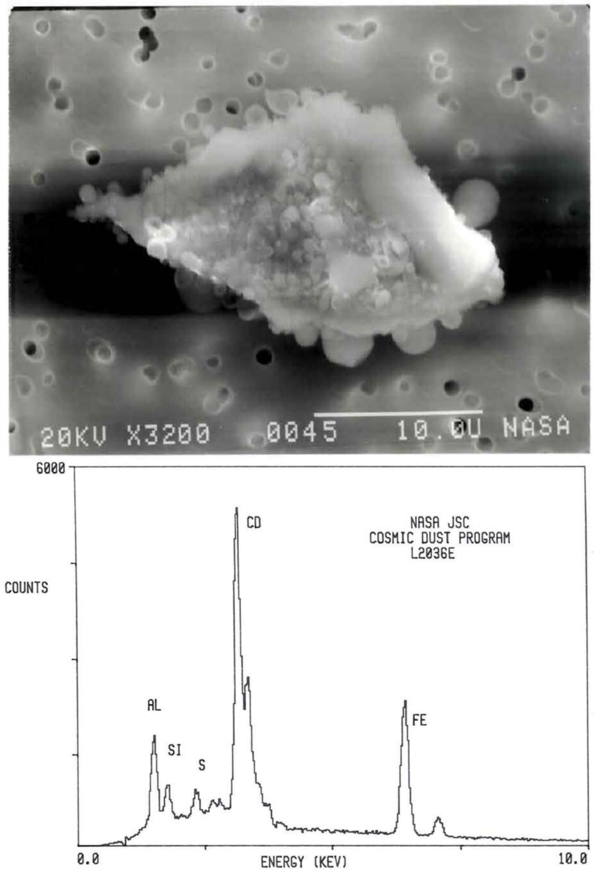

Figure 4: L2036E2. This particle is predominantly cadmium, probably originating from the gold-colored cadmium oxide coating used for corrosion protection on some hardware and fittings. The presence of sulfur indicates interaction with sulfuric acid, and the knobby appearance may originate from either sulfuric acid corrosion or heating on infall. Anecdotal evidence from recent collections suggests cadmium bearing particles are appearing more frequently recently.

References: [1] Murphy, D.M., et al 2023. *PNAS* 120(43), p.e2313374120. [2] Jain, A. and Hastings, D.E., 2022. In ASCEND 2022 (p. 4224).[3] Park, S.H., et al., 2021. *Acta Astronautica*, 179, pp.604-618.[4] Li, D., et al 2023. *Astrodynamics*, 7(4), pp.455-463. [5] Louis-Charles, H.M., et al., 2023. Risk, Hazards & Crisis in Public Policy. DOI: 10.1002/rhc3.12266 [6] Park, S.H., et al 2021. *Advances in Space Research*, 68(1), pp.1-24. [7] Bernelli-Zazzera, F., et al 2023. *CEAS Space J.*, 15(4), pp.553-565. [8] https://www.spaceflightinsider.com/missions/earth-science/impact-new-satellite-launch-trends-orbital-debris/